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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/786

Critique of the Cal. .50 AP M2 Projectile-Through-Plate Test and the 20 MM H.E.I. Shock Test Requirements of Spec. AXS-455, Rev. 3

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6 April 1954
12 Oct 56 Clyde R. Vorquites
date CLYDE R. VORQUITES
Chief,
Intell & Sec O

BY

A. Hurlich
Metallurgist

UNCLASSIFIED

DATE 19 October 1945

WATERTOWN ARSENAL
WATERTOWN, MASS.

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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT NO. WAL 710/786

Final Report on Job No. 160

19 October 1945

Critique of the Cal. .50 AP M2 Projectile-Through-Plate Test and the 20 MM H.E.I. Shock Test Requirements of Spec. AXS-488, Rev. 3

ABSTRACT

It is concluded from a comprehensive ballistic and metallurgical evaluation of three samples of 3/8" rolled homogeneous armor that:

a. In the penetration-through-plate tests of Spec. AXS-488-3 involving the use of cals. .30 and .50 AP M2 projectiles, the maximum acceptable exit diameters are too large, allowing the acceptance of armor of inferior ballistic characteristics.

b. Jacket-less caliber .50 AP projectiles can be developed for use in the projectile-through-plate test.

c. The 20 MM H.E.I shock test of Spec. AXS-488-3 is an integrative test possessing attributes both of shock and steel soundness tests. Although the 20 MM H.E.I. test does yield valuable information relative to the ballistic characteristics of armor, the development of a more suitable shock test is recommended.

1. Three samples of 3/8" rolled homogeneous armor processed by the American Car & Foundry Co. were forwarded to this arsenal from the Ordnance Research Center[1] for metallurgical examination. These plates had been subjected to ballistic tests in accordance with the then acceptance Specification AXS-495, Rev. 2 and also in accordance with the then development Specification AXS-488, Rev. 3. Two of the three plates failed to meet the ballistic requirements of Spec. AXS-488, Rev. 3.

2. The results of the metallurgical examination and of additional ballistic tests performed at this arsenal lead to the following conclusions and observations:

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1. APG 470.5/1536, Wtn. 470.5/8754, dated 14 May 1945.

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a. All three plates possess unsatisfactory steel soundness traceable to segregations of nonmetallic inclusions along planes approximately 1/8" below both plate surfaces.

b. This arsenal is of the opinion that, in the penetration-through-plate tests of Spec. AXS-488, Rev. 3 involving the use of Cals. .30 and .50 AP M2 projectiles, the maximum acceptable exit diameters are too large.

c. Jacket-less caliber .50 AP projectiles which may be suitable for the penetration-through-plate test have been developed at Watertown Arsenal (Ref. Watertown Arsenal Laboratory Memorandum Report No. WAL 762/320 "Considerations Preliminary to the Development of Improved PTP Test Projectiles").

d. The 20 MM H.E.I. test incorporated into Spec. AXS-488, Rev. 3 as a resistance-to-shock test for light gage armor up to 3/8" in thickness, although yielding valuable information regarding the ballistic characteristics of armor, is not a satisfactory shock test. (Ref. Watertown Arsenal Laboratory Report No. WAL 710/685, "Armor Plate Ballistic Testing").

e. The 20 MM H.E.I. test is an integrative test possessing the attributes both of shock and steel soundness tests. The development of a ballistic test which is more closely identifiable with the shock resistance characteristics of armor than the present 20 MM H.E.I. test is recommended.

3. Details of the tests follow:

a. Ballistic Tests Performed at APG

The ballistic testing of the subject armor plates was performed at Aberdeen Proving Ground during April and May 1945. Tests were performed in accordance with the then acceptance Spec. AXS-495-2 and the then development Spec. AXS-488-3. All plates were satisfactory under Spec. AXS-495-2 whereas plates Nos. J2516M and J2516T failed to meet the ballistic requirements of Spec. AXS-488-3. Although plate No. J2518M did meet the AXS-488-3 ballistic requirements, a backspall was obtained on the 20 MM H.E.I. shock test, see Table I.

It will be noted that 100% backspalls occurred in the cal. .50 AP M2 PTP test of all plates, although in only one plate did the backspalls exceed the maximum exit diameter of 1½" allowable under Spec. AXS-488-3 and thus lead to the rejection of the plate. It is understood that very large allowable exit diameters were selected for the cals. .30 and .50 AP M2 PTP tests to prevent the rejection of satisfactory quality armor because of excessive exit diameters resulting from the rejection of punchings produced by the balling up of the jackets of these projectiles which occurs at high striking velocities. The difficulties resulting from the use of jacketed small caliber armor piercing projectiles for the PTP test has long been recognized[2].

2. Rolled Armor Subcommittee Report No. 44. "Types of Failure Occurring in the Shock Test of ½" Homogeneous Armor with Caliber .50 A.P. Projectiles." N. A. Matthews, 6 May 1942.

It is the opinion of this laboratory that the acceptance of armor which develops backspalls as large as three calibers in diameter under the PTP test allows the acceptance of a considerable amount of armor of inferior and very questionable soundness. The maximum allowable exit diameters in the PTP test of Spec. AXS-488-3 in which cals. .30 and .50 AP M2 projectiles are used are considered excessive.

As the result of the deficiencies of jacketed projectiles, the Watertown Arsenal had been requested by the Office, Chief of Ordnance[3], to develop jacket-less cal. .50 AP projectiles to be used for the PTP test of light armor. Three types of projectiles were accordingly developed[4] and samples were shipped to the Ordnance Research Center for testing. Additional firing at one of the subject plates was performed at this arsenal using some of the jacket-less projectiles. These tests will be described later.

Plate J2516M failed the 20 MM H.E.I. shock test through backspalling upon partial penetration, see Figure 2B. The backspalling was obviously due to a lamination in the steel both because of its appearance and because the plane of the backspall coincided with those of backspalls caused by the cal. .50 AP M2 projectiles used in the PTP test. As explained in Watertown Arsenal Laboratory Report No. WAL 710/685 "Armor Plate Ballistic Testing," the 20 MM H.E.I. test is not considered a satisfactory shock test. This test does, however, provide valuable information regarding the ballistic characteristics of light armor. The test is actually integrative in nature, possessing attributes both of shock and steel soundness tests. Thus, as will be shown later, plate No. J2516M failed the shock test not because of reduced resistance to shock impact but because of poor steel soundness. This plate showed a fibrous fracture and should therefore possess good resistance to shock.

It is the opinion of this laboratory that failure to meet the specified ballistic limit value or the occurrence of excessive cracking should not be the only criteria of failure in the 20 MM H.E.I. test. The revelation of steel unsoundness by the formation of backspalls upon complete penetration should also lead to rejection of the armor. If backspalling upon complete penetration during the 20 MM H.E.I. test were also a criterion of failure, all three of the subject plates would have failed the chock test. The use of a minimum ballistic limit criterion in a shock test is not viewed with favor because the physical characteristics leading to a high resistance to penetration are often the same that result in low resistance to shock. It is believed that the most useful and valid information obtainable from the 20 MM H.E.I. test is based upon the occurrence of cracking or backspalling when the projectile is fired at a velocity below the ballistic limit of the armor.

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3. OCM. 400.112/Wtn Ars (2-23-45) - Wtn. 470.5/175, 23 Feb. 1945.
4. Watertown Arsenal Memorandum Report No. WAL 762/320(r). "Considerations Preliminary to the Development of Improved PTP Test Projectiles." J. F. Sullivan, 26 June 1945.

b. Ballistic Tests Performed at Watertown Arsenal

Projectile-through-plate tests were performed upon plate No. J2518M using cal. .50 AP M2 projectiles at velocities from 2200 ft./sec. to 2880 ft./sec. and experimental cal. .50 jacket-less AP projectiles, types S-2 and S-3, at velocities of approximately 2000 ft./sec. The latter projectiles have 1.5 and 2.0 caliber ogives respectively, and are fully described in Watertown Arsenal Laboratory Memorandum Report No. WAL 762/320(r). Photographs of the back of the armor after ballistic testing are shown in Figure 1 and the details regarding the exit conditions are contained in Table II.

At velocities up to at least 2500 ft./sec. the cal. .50 AP M2 projectile produces full petalling with no evidence of backspalling. A 100% backspall 1"x1" in size was produced at a velocity of 2880 ft./sec. The cal. .50 jacket-less AP projectiles types S-2 and S-3 produced 100% backspalls in all cases at velocities of approximately 2000 ft./sec. These backspalls ranged in size from 7/8"x7/8" to 15/16"x3/4". These results indicate that the jacket-less projectiles may be suitable for the PTP test of light gage armor.

It was observed that the backspalls, including those produced at Aberdeen Proving Ground and at Watertown, occurred in all cases upon a plane approximately one third of the thickness below the surface of the armor. The appearance of the backspalled regions was typical of those of laminated steel.

c. Steel Soundness Fracture Tests

Two sections, one 90° to the other, were prepared from the three armor sections for steel soundness fracture tests. The results follow:

	Fracture Specimen No. 1		Fracture Specimen No. 2 90° to No. 1	
Plate No.	Steel Soundness Rating	Fibre Rating	Steel Soundness Rating	Fibre Rating
J2516M	B	F	D	F
J2516T	B	F	D	F
J2518M	B	F	D	F

It was impossible to accurately ascertain which fracture specimen was taken transversely and which was taken longitudinally to the major direction of rolling. The steel had not been well cross-rolled as evidenced by the poor steel soundness rating in one direction and the satisfactory soundness rating in a direction perpendicular to the first. This emphasizes the necessity for either taking the steel soundness fractures in both directions or taking one fracture specimen in the direction known to best reveal the true soundness rating, namely, in the longitudinal direction and notched so as to provide a transverse fracture. The fracture specimens which yielded the "D" soundness ratings were most probably taken longitudinally to the major direction of rolling.

It was noted that the laminations in the specimens showing "D" quality fractures occurred on two planes, each approximately 1/8" below one of the plate surfaces, see Figure 2B. These planes containing the laminations are the same upon which all backspalls occurred. It is believed that the distribution of nonmetallics revealed by the fracture test is the result of the persistence of an original ingot segregation.

Fibrous fractures obtained in all samples indicate that the steels were properly heat treated and undoubtedly possess satisfactory shock resistance characteristics. The fact that one of the plates failed the 20 MM H.E.I shock test in spite of its adequate resistance to shock offers further proof to the contention that the 20 MM H.E.I. test is an integrative test rather than a pure shock test.

d. Brinell Hardness Surveys

Three Brinell hardness readings were obtained upon ground sections of the three plates with the following results:

Plate No.	Individual BHN Readings
J2516M	363-363-363
J2516T	363-363-363
J2518M	375-375-375

e. Hot Acid Macroetch

Longitudinal and transverse sections cut from the three plates were subjected to hot acid macroetching. A high concentration of pitting was observed at the boundaries of the middle third of the cross-section of all plates, indicative of local segregations of nonmetallics.

A photograph of a hot acid etched section cut through penetrations of a cal. .50 AP M2 and of an experimental cal. .50 AP jacket-less projectile is shown in Figure 2A. The middle third ingot pattern is evident in the photograph. Although no spalling resulted from the penetration of the cal. .50 AP M2 projectile, extensive cracking is noted along the plane of the ingot pattern. Full backspalling has occurred along the same plane in the case of the penetration of the jacket-less projectile.

f. Microscopic Examination

Metallographic examination of polished cross-sectional surfaces of the three plates revealed identical segregations of small silicate inclusions in all three plates, Figure 2C. These inclusions were concentrated along the same planes previously described. The inclusions were much more elongated in the direction corresponding to Figure 2C than in the direction transverse to the former.

5. In view of the experience gained from the examination of the subject plates, it is recommended that the maximum allowable exit diameters presently specified in AXS-488-3 be lowered in the cases of the cals. .30 and .50 AP M2 PTP tests. It is further recommended that jacket-less projectiles for use in

the PTP test of light gage armor be more fully investigated. Consideration should be given to the development of a shock test which is more closely identifiable with the shock resistance characteristics of armor than is the present 20 MM H.E.I. test.

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Metallurgist

APPROVED:

E. L. Reed
E. L. REED
Research Metallurgist
Chief, Armor Section

TABLE I

Ballistic Tests Performed under Spec. AXS-488-3

Plate No.	Armor Test Report No.	Ballistic Limit Cal. .30 APM2 Reqd. Vel. Ft./Sec.	Ballistic Limit Cal. .30 APM2 Actual Vel. Ft./Sec.	PTP Test Cal. .50 APM2 Vel. Ft./Sec.	PTP Test Cal. .50 APM2 Max. Exit Diam.	Shock Test 20 MM H.E.I. 0° Obliquity Ballistic Limit Reqd. Vel. Ft./Sec.	Shock Test 20 MM H.E.I. 0° Obliquity Ballistic Limit Actual Vel. Ft./Sec.	Results
J2516M	Ar-16205	1640	1698	2790	1-1/8"x1-3/16" w/100% BS	2050	2510	PP(A) resulted at vel. of 2472 ft/sec. which was CP(P) because of circular backspall 1-5/8"x1-11/16" thrown off.
		Satisfactory		Satisfactory		Failed		
J2516T	Ar-16204	1644	1700	2803	1½"x1-9/16" w/100% BS	2054	2499	2482 ft/sec. - PP(A) Star cracks 1" and 1-1/4" 2516 ft/sec. CP(A) crack of light, circular B.S. 1-3/4"x1-7/8" thrown off.
		Satisfactory		Failed		Satisfactory		
J2518M	Ar-16203	1644	1742	2822	1-1/8"x1-1/4" w/100% BS	2054	2617	2637 ft./sec. - CP(A) 1" crack. Exit diam. w/50% B.S. - 1-3/16"x 1-5/8".
		Satisfactory		Satisfactory		Satisfactory		

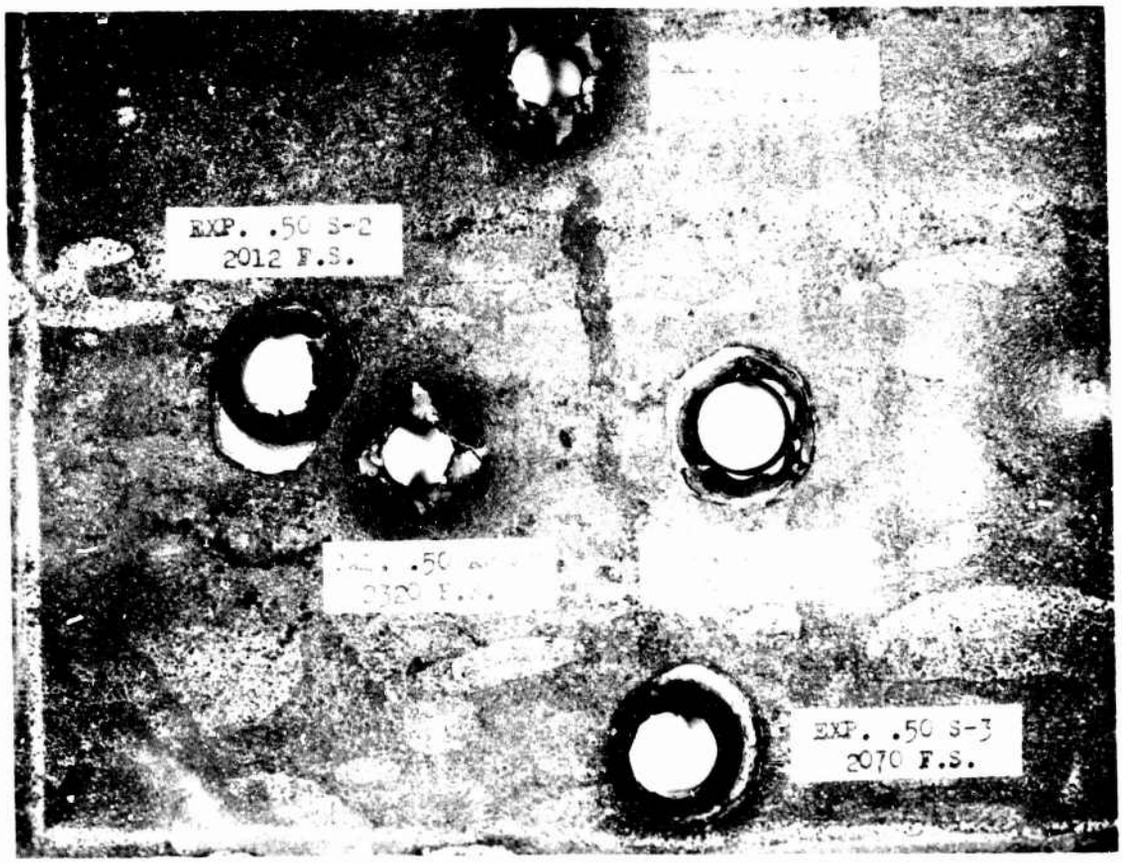
TABLE II

Ballistic Tests Conducted at Watertown Arsenal

Projectile-Through-Plate Test

Plate No. J2518M

Projectile	Velocity Ft./Sec.	Exit Diameter	Condition of Back of Penetration
Cal. .50 AP M2	2200	3/8"x3/8"	Full Petalling
Cal. .50 AP M2	2320	3/8"x3/8"	Full Petalling
Cal. .50 AP M2	2495	3/8"x3/8"	Full Petalling
Cal. .50 AP M2	2880	1"x1"	100% Back Spall
Expt'l Cal. .50 S-2	2012	15/16"x3/4"	100% Back Spall
Expt'l Cal. .50 S-2	2040	7/8"x7/8"	100% Back Spall
Expt'l Cal. .50 S-3	2066	7/8"x7/8"	100% Back Spall
Expt'l Cal. .50 S-3	2070	7/8"x7/8"	100% Back Spall


EXP. .50 S-2
2012 F.S.
EXP. .50 S-3
2070 F.S.

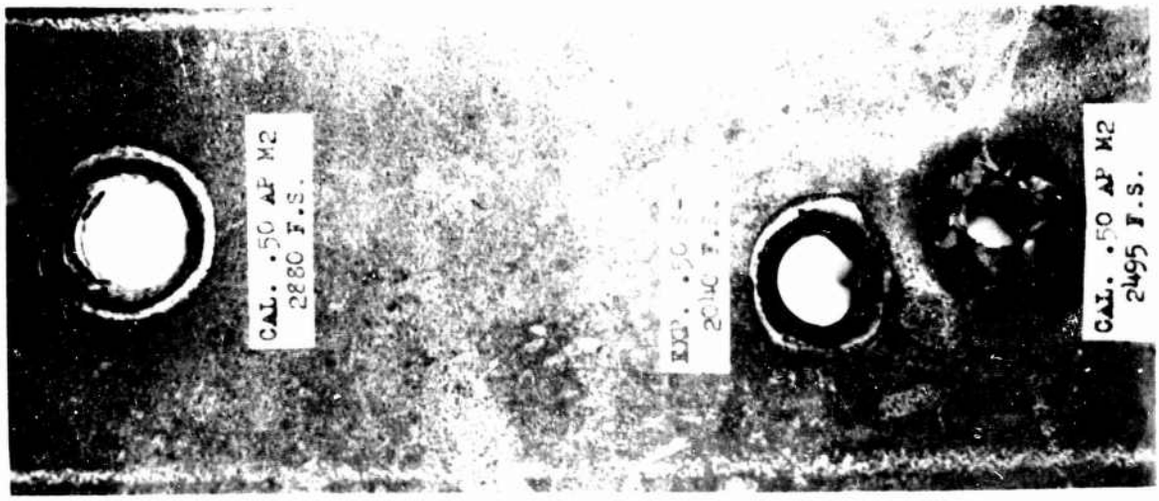

CAL. .50 AP M2
2880 F.S.
CAL. .50 AP M2
2495 F.S.

FIGURE 1

American Car & Foundry 3/8" Plate No. J2518M

Cross-section of penetration of Cal. .50 APM2 at 2495 ft./sec. Full petalling, no spalling.

-A-

Cross-section of penetration of experimental unjacketed Cal. .50 projectile at 2040 ft./sec. 100% backspall.

Mag. X2
Hot Acid Etched

Plate No. J2516M

-B-

Mag. X1

Left

Photograph of steel soundness fracture.

"D" Quality Fracture.

Right

Back of plate after 20 MM. H.E.I. test. Partial penetration.
Diameter of rejected backspall 1.6".

Typical segregation of small silicate nonmetallics concentrated along planes approximately 1/8" below both plate surfaces.

Unetched

-C-

Mag. X100

FIGURE 2